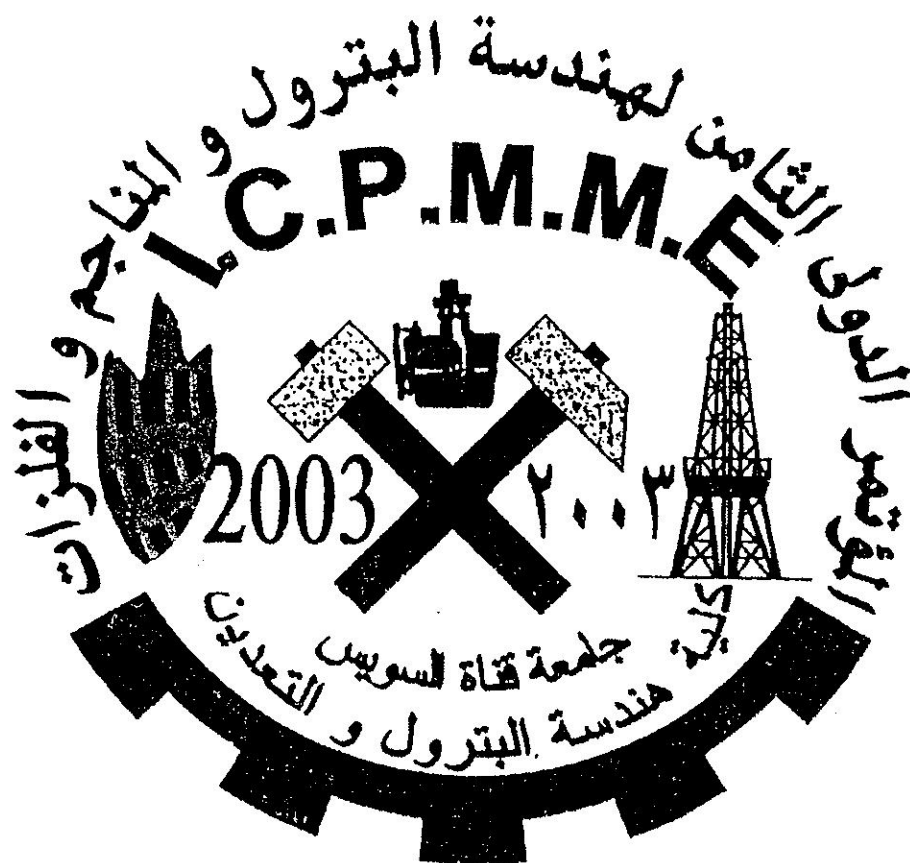


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GEOSTATISTICAL STRUCTURAL ANALYSIS OF GHORABI IRON ORE DEPOSIT

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ABSTRACT:

Ghorabi iron ore deposit is one of many iron ore deposits of Bahariya Depression in the Western Desert. The present work aims to study the variability of iron content of Ghorabi area within different zones by using geostatistical technique. These individual zones are the result of the stratigraphic and structural setting of ore deposit. To achieve our purpose, directional variograms have been constructed within each zone to examine the presence of directional anisotropy of the orebody. Then, global variogram has been constructed for each zone to study the characteristics of iron content within the different zones to show zonal anisotropy within the orebody. Both directional and zonal anisotropy as reflected by the variogram parameters could be used to illustrate the effect of faults and mineralization type on the orebody and hence the effect of taking the geological characteristics into account when applying geostatistical analysis for Ghorabi iron ore evaluation.

INTRODUCTION:

Geostatistical analysis through the construction of variograms, with the aid of a computerized database, plays an important role in studying the behavior of the orebody, for example, the continuity and nature of mineralization and its variation in grade over the deposit by considering the positions of the available samples within

any deposit (1). When constructing variograms, the samples must belong to one zone to represent the spatial variability of that zone (2). These zones can be defined by studying the geology of the ore body including its structural, mineralogical, and chemical properties. The database is then created for a specific zone, in which all segments are assumed to have the same geological features.

Based on previous geological studies, which were carried out on the Ghorabi iron ore deposit, it is clear that the orebody could be divided structurally and stratigraphically into four zones. This division might affect the mineralogical characteristics of the orebody and the ultimate ore reserve calculation. However, this could be investigated through geostatistical modeling of the orebody by considering its geology and hence variograms have been constructed for individual different zones.

For sake of comparison, it is then assumed that the structural geology has no effect on the mineralization of the orebody, and the deposit whole area is considered as one zone for which variograms could be constructed.

To clarify the advantage of geostatistical analysis over conventional statistical analysis, the distribution of iron content and its parameters; mean, standard deviation and coefficient of variation, within these zones has been performed statistically. This statistical analysis could refer to different characteristics of iron content within the different zones.

GEOLOGY OF GHORABI OREBODY:

Gabal Ghorabi is located on the trace of a giant dextral right stepping wrench fault system that extends further in the northeast direction. In the mean time the master-fault affecting Gabal Ghorabi makes two levels of iron ore, one high to the north occupying the foot-wall while the lower iron ore level is situated in the hanging-wall (3).

Ore geology and ore genesis :

The orebody could be classified into the following types (3):

(a) Stratiform Cenomanian ironstones:

This ore type forms stratiform layers and lenses of variable thicknesses, confined to the upper mudstone dominated member of the Cenomanian Bahariya Formation. The ore is of muddy nature and ore layers and lenses often intercalated by glauconitic mudstones and siltstones.

(b) Stratiform to stratabound Middle-Eocene ironstones comprising:

- Stratiform oolitic or oolitic-nummulitic ironstones (3-6 m in thickness) deposited directly on the Cenomanian clastics and the associated ironstones representing formation under shallow marine condition (3).
- Stratabounded surficial duricrust developed oolitic-pisolitic ironstones which form the hard cap demarcating the summit of gabal Ghorabi. The ore is of brecciated nature dominated by crustified textures or cave fillings formed as a result of subaerial denudation of pre-existing iron rich sediment.

STRUCTURAL MODEL:

Further north, the northeastern plateau is affected by another giant right-lateral fault, known as the Ghorabi fault system (Fig 1). This fault system extends through the Eocene sequences to the north of the Depression. It brought the Cenomanian clastics

and the related ironstone to within the plateau area in the Ghorabi mine area and further to the northeast.

The fault system affected the Eocene carbonates with extensive folding along the whole fault course. On the other hand, the amplitude of the cretaceous folds is rather greater than that of the Eocene built-up folds, indicating successive phases of fault displacement during the Cretaceous-Eocene time (3,4).

The Cenomanian ironstone is thought to be preserved at shallow depths along this fault system. In the Ghorabi mine area, this master fault principally crosses the Cenomanian clastics with pronounced strain gradients, where the blocks to the north and south of the fault are strongly folded.

The axial traces of these folds are oriented in North east-South west direction, as the plunge direction. The fold forms a right-stepping en-échelon pattern and the limbs facing the master fault are steeper than the others. These folds are restricted to the Cenomanian beds and Eocene nummulitic limestones of high relief from their limbs. The Ghorabi iron ore rests horizontally on the fold area.

The master fault affecting Gabal Ghorabi splits the Lutetian iron ore into two levels, one higher to the North occupying the foot-wall, the other lower situated in the hanging-wall. From this discussion one can conclude that the iron ore of Gabal Ghorabi is over-printed on pre-existing Cenomanian and Eocene ironstone, and now appears as a horizontal surficial ferricrete duricrust (5). Ghorabi area is also crossed by North-West normal faults displacing the iron levels up to several meters. These faults have at least two episodes of displacement. The first phase affected the Cretaceous beds with strain rotation, while the second phase affected the iron levels with a transitional type of regime (6).

OREBODY ZONES:

Study of the geology of Ghorabi area; including faulting, folding, and stratigraphy of the ore body, revealed that it could be divided into four different zones; north (N), east (E), central (C), and south (S) Ghorabi as shown in the Fig.2.

AVAILABLE DATA:

The present study is based on sampling information derived from (100 x 100m) drill-hole grid system comprising 191 drill-holes. For each zone, a database has been established using only the drill-hole data, which fall, within each zone. Later, all the databases were merged into one to represent the whole area. For each drill-hole, co-ordinates and iron content were provided in the database.

STATISTICAL ANALYSIS:

Statistical analysis gives the distribution of iron content and the standard parameters; mean, standard deviation, and coefficient of variation. The histograms in Fig. 3 illustrate that the iron content does not have the same distribution within the different zones. The average iron content of zones (N), (E), and (C) as shown in table 1, seems to have values approximately near to each other while zone (S) recorded the highest value. On the other hand, coefficient of variation values are low within the four zones and hence the iron content does not change widely within the orebody.

Traditional statistical methods are based on the assumption that all sample values are equally representative of the deposit under study, and the physical positions of the

samples with respect to each other are not taken into account (2). This could be considered a reason for the coefficients of variation not to give any clear difference between the studied zones and hence reflects the insufficiency of traditional statistics in analyzing the variability of Ghorabi orebody.

Geostatistical analysis, which allows the relative sample positions to be taken into account, can therefore be used to check this supposition.

CONSTRUCTING VARIOGRAMS:

Construction of an experimental variogram is the first step in any geostatistical analysis. It can be computed from a set of randomly spaced data through finding pairs of data that are oriented in the required direction, determining the distance between the samples, then summing the squared differences of the grades and dividing by the number of pairs (1).

Constructed variograms reflect the variability of the ore mineralization and could be used to differentiate between characteristics of the different zones of an orebody and as a base of the next steps in the geostatistical evaluation, such as kriging. To illustrate the effect of geology of the orebody, directional variograms have been constructed for each zone and for the whole area to check the directional anisotropy characteristics for each case and for the whole area.

TechBase software, which is a system designed to aid geologists and engineers in mine evaluation and mine planning, was used to construct the variograms. According to the data arrangement, the required parameters for constructing variograms were introduced to the program. A lag interval of 100 m with 10% tolerance was considered when constructing horizontal variograms. When the directional variograms were constructed, the azimuth (bearing, clock-wise from north) was considered as 0° for N-S, 90° for E-W, 45° for the diagonal direction NE-SW and 135° for NW-SE with a 22.5° tolerance for any direction.

Directional anisotropy:

Directional variogram reveals the change in the variogram parameters as the direction changes (7). The directional variograms for the whole area as shown in Fig. 4 demonstrate the absence of anisotropy when Ghorabi iron deposit is considered as one zone and the geological characteristics are neglected.

The variogram curves are sufficiently close to each other through the different directions and appear to be the same. Also, the fitted spherical models through the four directions, as shown in Fig. 9, do not show any clear differences. This information is also shown in Table 2. The orebody of Ghorabi area, at this point, could be considered isotropic when neglecting the effect of its geologic structure.

However, when considering the effect of the geology of the orebody, i.e., considering both of faults and stratigraphy of the orebody, directional variograms within the different zones reflect the presence of directional anisotropy through the different zones. The appearance of linear model on some directional variogram reflects high continuity through these directions, i.e., the ore mineralization is considered to have low variability. Direction NE-SW through zones (S) and (E), E-W of zones (E) and (C), N-S of zone (N) give higher continuity than other directions. Also, the low values of C_0 and C on the spherical models of the other directional variograms illustrate that the ore mineralization varies from one direction to another within narrow range.

Zonal anisotropy:

The variogram behavior can vary within the different zones of the orebody indicating the presence of zonal anisotropy. To prove the presence of zonal anisotropy within Ghorabi iron ore deposit and to support the concept of dividing the orebody into zones according to its geologic setting, global variograms have been constructed for two cases; the first one considers the orebody of Ghorabi area as one zone and the second is to divide it into different zones. The results for both cases are shown in Fig. 14 and Table 3.

The variograms for the different zones illustrate that the variability of the orebody is not the same for all of them. Zone (N) as shown in Fig. 14 gives the least variability and hence the best mineralization continuity while zone (C) shows the highest variability.

Such geostatistical structural analysis confirms, and hence justifies the idea of considering the geologic setting as a main factor affecting the evaluation process by geostatistical technique. Detailed inspection of the effect geologic setting on geostatistical structural analysis of Ghorabi mineralization is highly recommended.

CONCLUSION:

A geostatistical study carried out on iron ore deposit showed the following:

- 1- The possibility of dividing the ore deposit into different zones according its geologic setting.
- 2- Statistical analysis did not give enough information about the variability of iron content within the orebody where low coefficient of variation values were recorded for the different zones and hence the orebody could be considered isotropic from the statistical point of view.
- 3- Directional variograms showed that the continuity of the mineralization of the orebody changes clearly from one direction to another to prove the presence of directional anisotropy and different mineralization characteristics for different zones. Consideration of orebody anisotropy could be useful in mine planning and production.
- 4- Zonal anisotropy also has been proved through zonal variograms where zone (N) has the highest continuity and zone (C) has the lowest continuity. This result may indicate that Ghorabi orebody is a multiorigin deposit; i.e., different types of ore and zonal anisotropy were found.

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Table (1): Statistical Parameters

Zone	mean	S.D.	Cov
N	46.97	2.8	0.06
E	47.07	3.9	0.08
C	46.42	4.4	0.09
S	51.34	3.1	0.06
Ghorabi	48.96	4.00	0.08

Table (2): Directional variogram parameters

ZONE		N-S	E-W	NE-SW	NW-SE
Ghorabi	Co	0.5	0.7	0	0
	C	11.9	11.4	14.8	11.3
	a	320	320	300	300
(N)	Co	0	0	0	1.07
	C	without	12.5	7.0	12.4
	a	without	300	220	250
(C)	Co	0	1.1	0.6	0.75
	C	8.9	without	11.8	14.6
	a	300	without	300	300
(E)	Co	0	0	0	0
	C	15.6	without	without	11.7
	a	300	without	without	250
(S)	Co	0	0	1.4	0
	C	9.9	12.1	without	9.0
	a	300	300	without	300

Table (3): Zonal variogram parameters

ZONE	Range of influence	Sill	Nugget effect
Ghorabi (T)	400 m	13.9 % ²	0 % ²
(E)	350	16.5	0
(N)	200	7.4	0.5
(C)	200	16.5	2.5
(S)	400	12.2	0

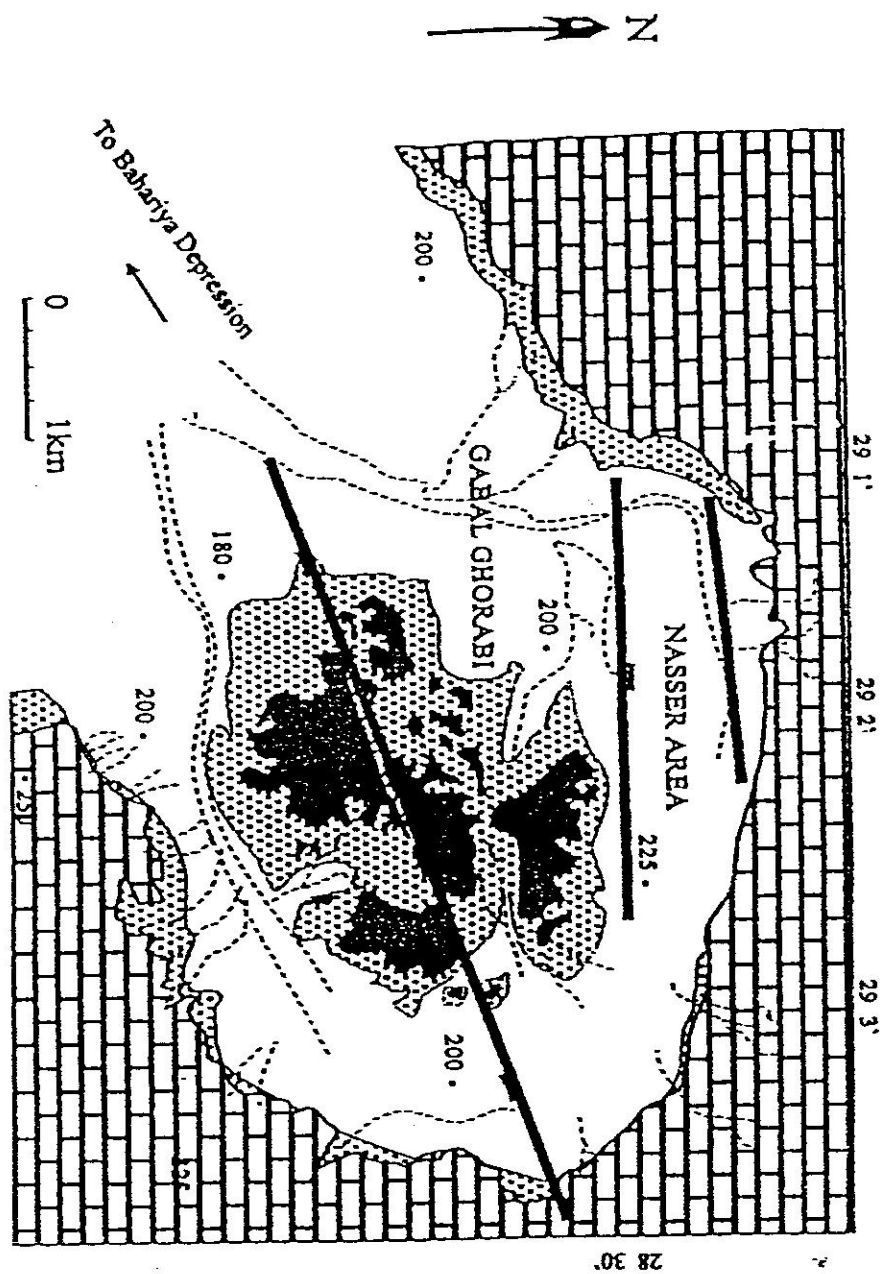
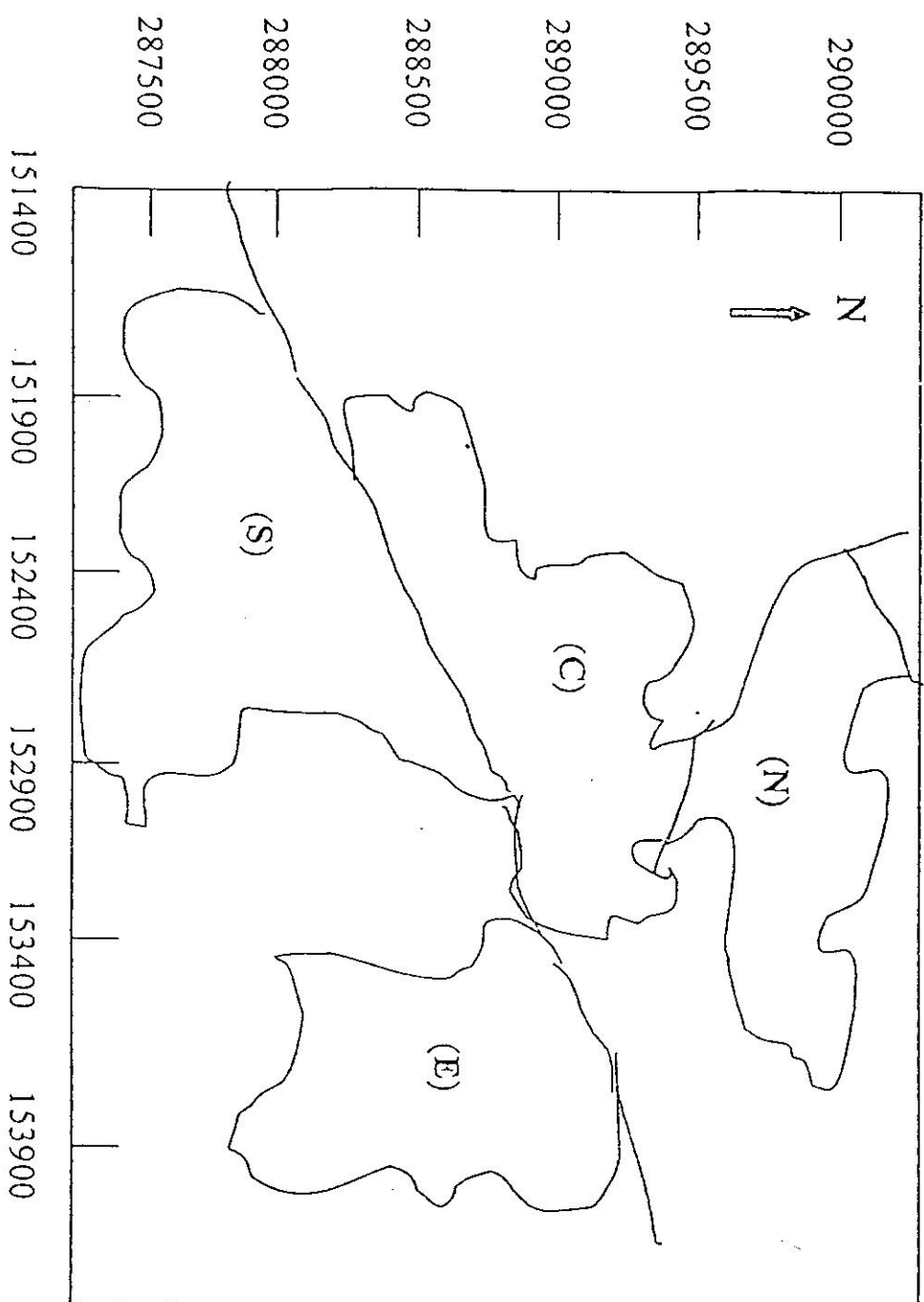
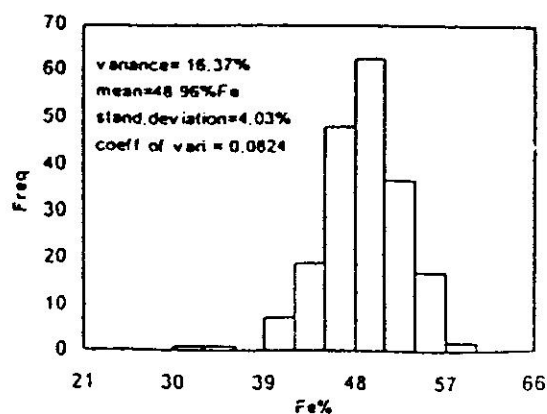


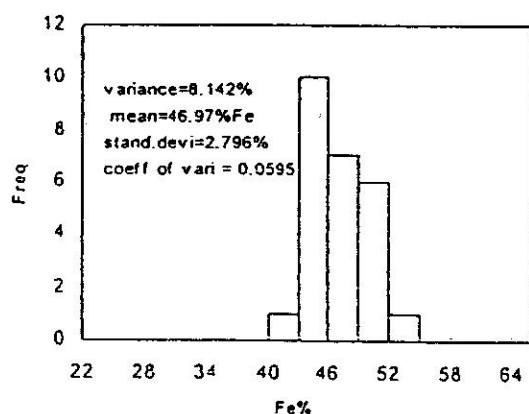
Fig. 1: Simplified geological map of Ghorabi - Nasser area (simplified after El Aref and Lotfy, 1989)
 1 = Clastic rocks of the Cenomanian Bahariya Fm.; 2 = karstified limestones of the Middel Eocene Naqb Fm.
 3 = Iron ore deposits; 4 = Quaternary sediments; 5 = Faults; 6 = Drainage lines

Fig 2. Zone Divisions of Ghorabi-area.

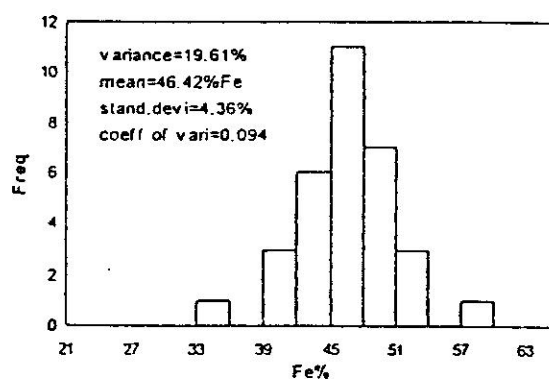




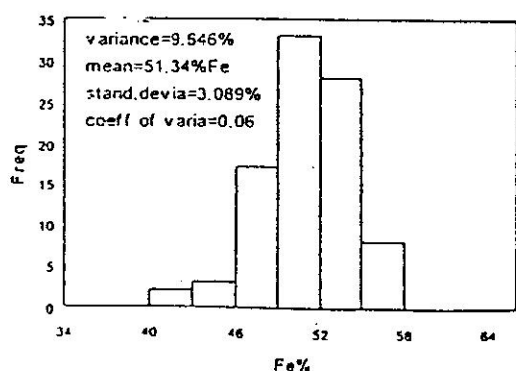
Histogram of the whole Ghorabi area



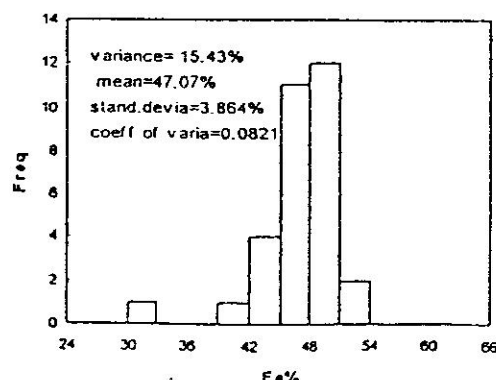
Histogram of north Ghorabi



Histogram of central Ghorabi



Histogram of south Ghorabi



Histogram of east Ghorabi

Fig 3. Distribution of Iron Content within the Different Zones and the whole area

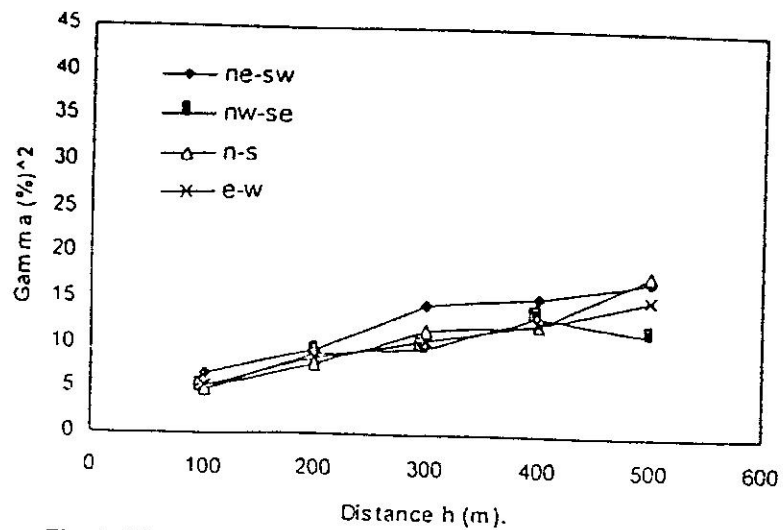


Fig 4. Directional Variogram for the Whole Ghorabi area (T).

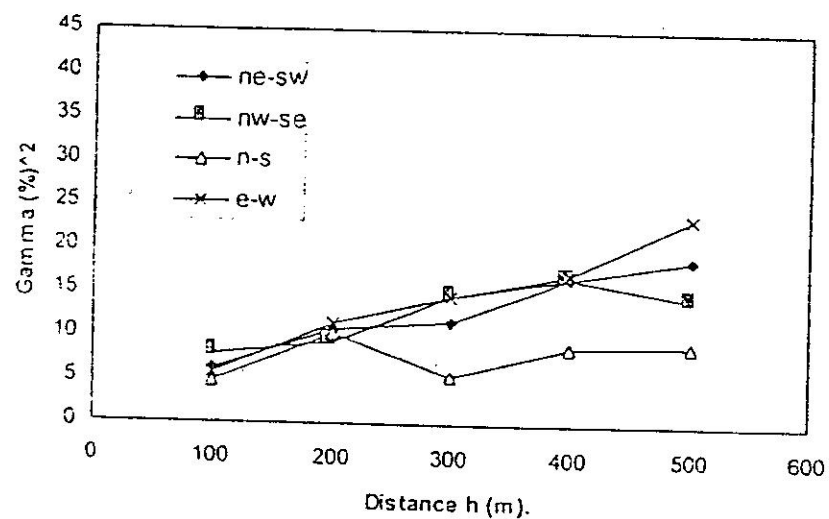


Fig 5. Directional Variogram for the Central Zone (C).

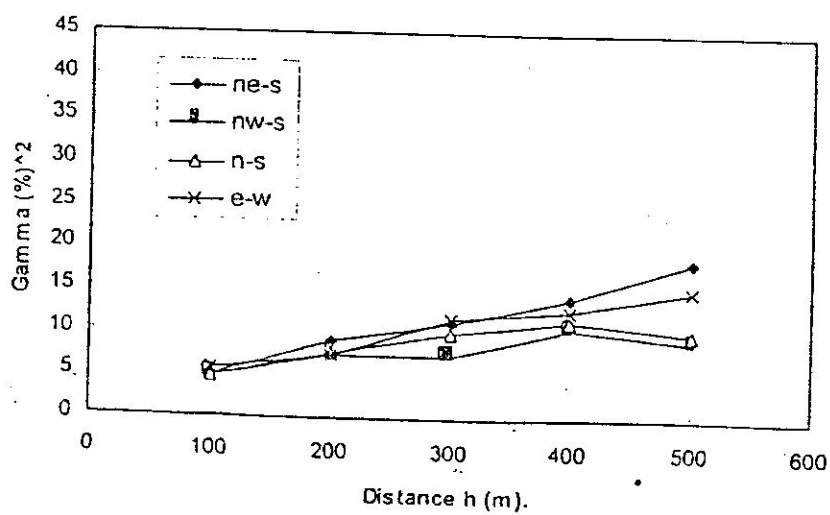


Fig 6. Directional Variogram for the South Zone (S).

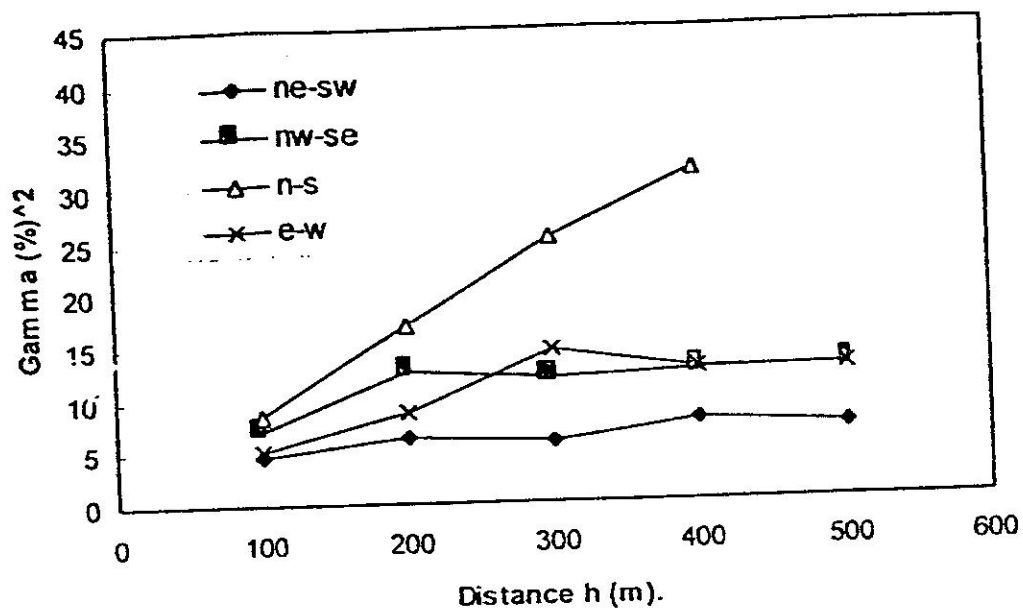


Fig 7. Directional Variogram for the North Zone (N).

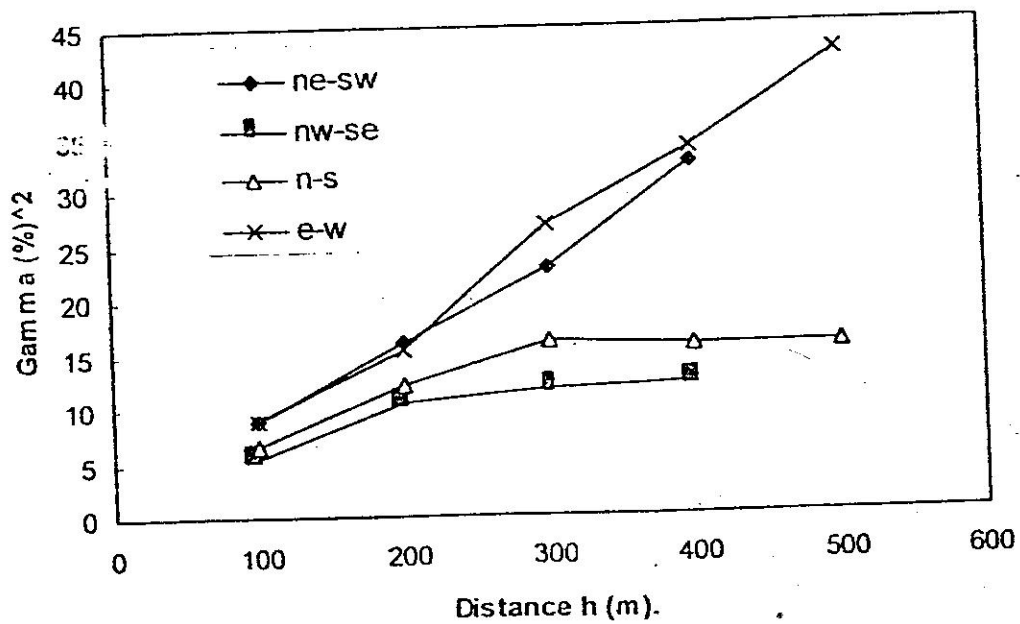


Fig 8. Directional Variogram for the East Zone (E).

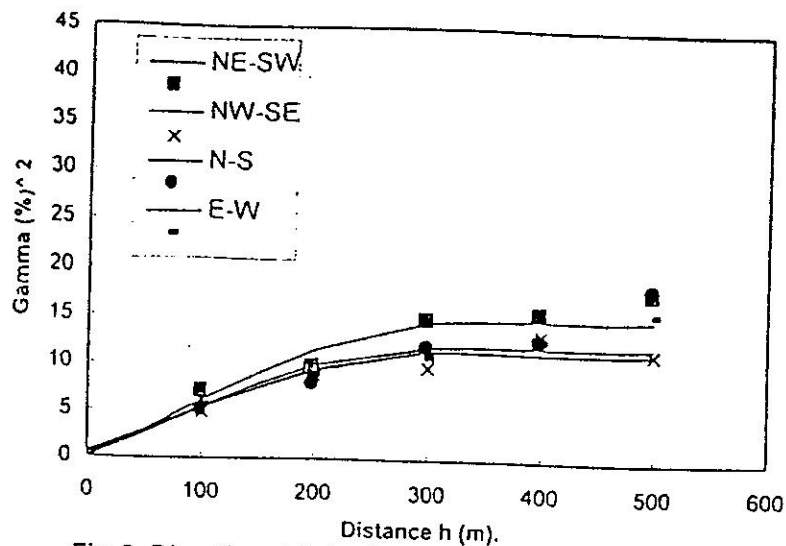


Fig 9. Directional Spherical Variogram Models for the Whole Ghorabi area (T).

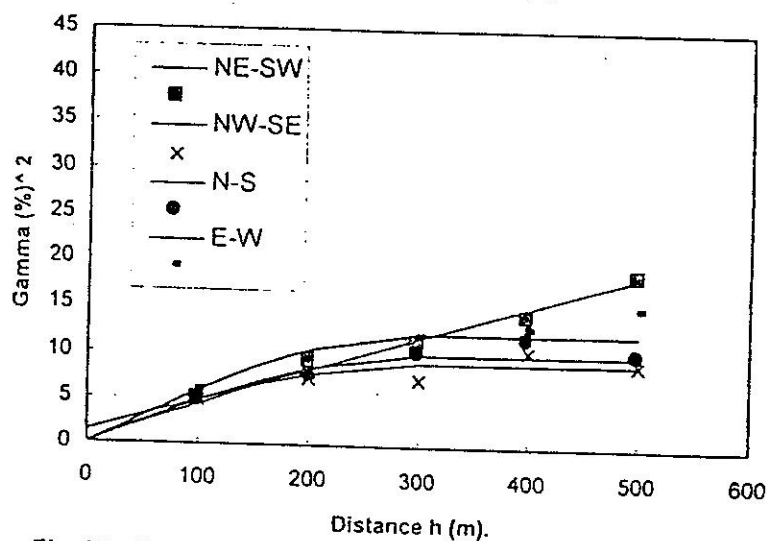


Fig 10. Directional Variogram Models for the South Zone (S).

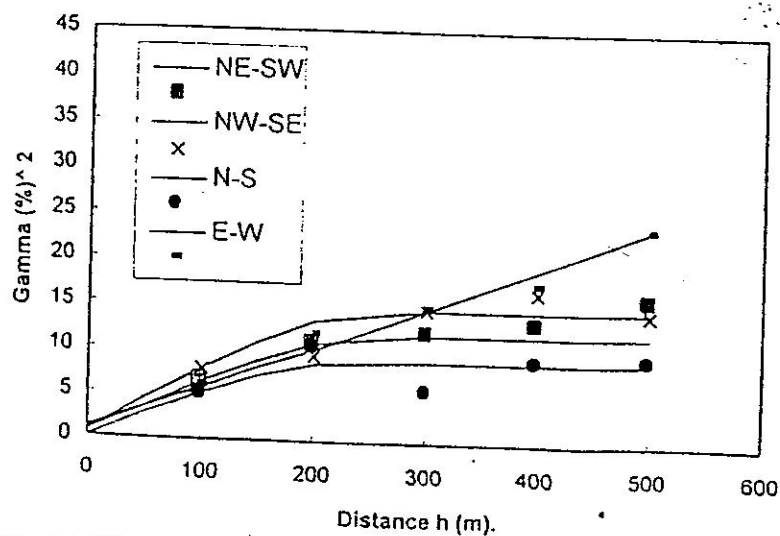


Fig 11. Directional Variogram Models for the Central Zone (C).

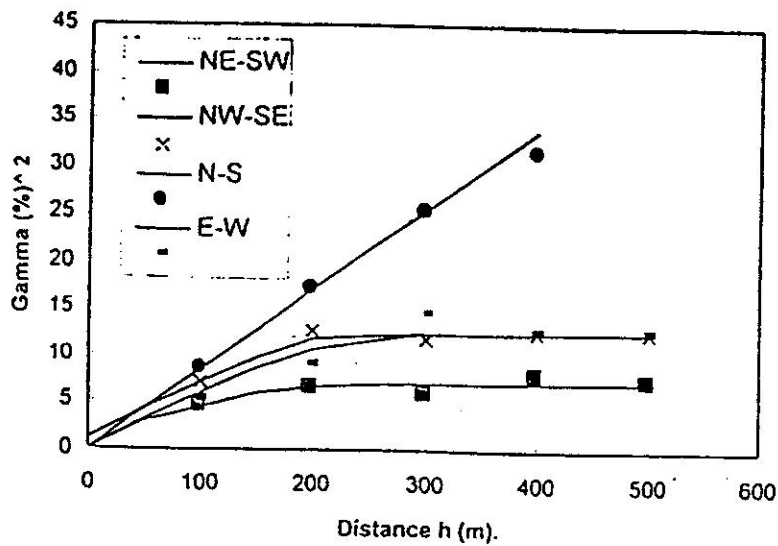


Fig 12. Directional Variogram Models for the North Zone (N).

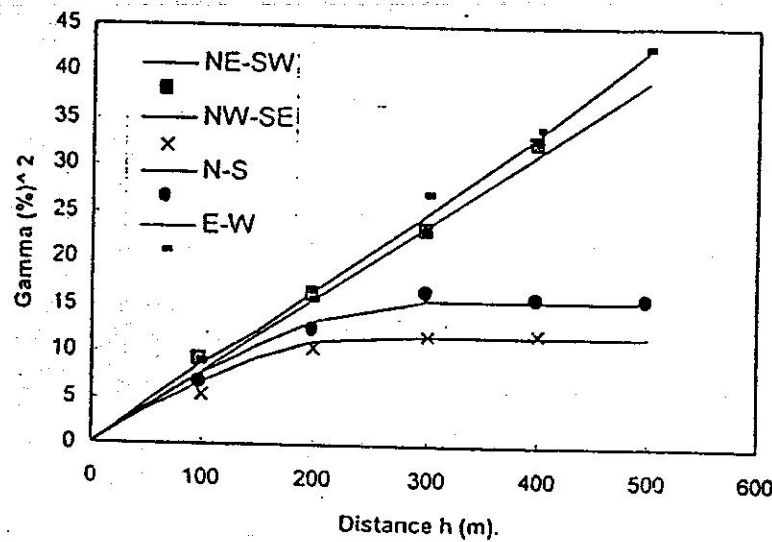


Fig 13. Directional Variogram Models for the East Zone (E).

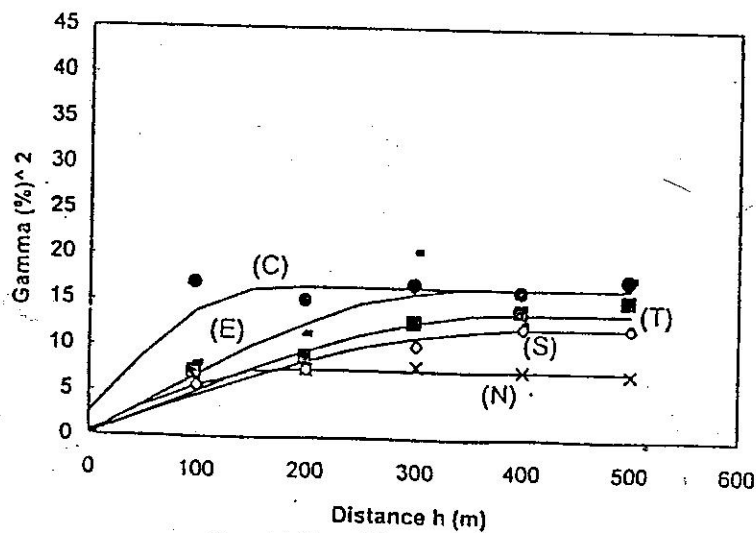


Fig. 14 Zonal Variogram Models.